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Foliage Plants for Removing Indoor Air Pollutants from Energy-efficient Homes[1]

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A sealed, Plexiglas chamber with temperature and humidity control and illuminated externally with wide spectrum grow lights was used to evaluate the ability of golden pothos (Scindapsus aureus), *nephthytis* (Syngonium podophyllum), *and spider plant* (Chlorophytum elatum *var.* vittatum) *to effect the removal of formaldehyde from contaminated air at initial concentrations of 15–37 ppm. Under the conditions of this study, the spider plant proved most efficient by sorbing and/or effecting the removal of up to 2.27 μg formaldehyde per cm² leaf surface area in 6 h of exposure. The immediate application of this new botanical air-purification system should be in energy-efficient homes that have a high risk of this organic concentrating in the air, due to outgassing of urea-formaldehyde foam insulation, particleboard, fabrics and various other synthetic materials.*

The accumulation of gaseous toxic substances in the air of poorly ventilated places has been known for many years, but only in recent years recognized as a potential indoor health hazard in energy-efficient homes (National Research Council, 1980, 1981a,b). Owing to the ubiquitous and increasing use of resins and solvents in most materials found inside modern homes, indoor air pollutants such as formaldehyde have increased significantly over the past years. The adoption of energy-saving proposals to reduce ventilation rates in homes has aggravated problems of indoor air quality and increased potential health hazards. One study of an energy-efficient home with an average air change per hour of 0.2 ach found the unoccupied and occupied dwelling to contain an average formaldehyde concentration of 80 $\mu g/m^3$ (0.067 ppm) and 240 $\mu g/m^3$ (0.2 ppm), respectively. New mobile homes with air change rates of 0.16 ach were found to contain 40–2,900 μg CH_2O/m^3 (0.03–2.4 ppm) (National Research Council, 1981b). Irritation of the eyes, throat and lungs, respiratory disorders, and allergies have been associated with high formaldehyde concentrations (Porter, 1975; Rostenberg et al., 1952; Roth, 1969; Shipkovitz, 1968; Tabershaw et al., 1979; Vehara, 1978; Wayne et al., 1976).

NASA at the National Space Technology Laboratories in Mississippi has conducted research for many years using natural processes for waste recycling and air purification and revitalization for closed ecological life-support systems (Wolverton, 1980, 1982; Wolverton and McDonald, 1981). Recently, research at this laboratory has been directed toward the development of a biological air-purification system for closed systems such as space stations and energy-efficient homes using houseplants that produce abundant foliage. This report presents data from this project. The common spider plant (*Chlorophytum elatum* (Ait.) (R.Br.) var. *vittatum* Hort.) (*McDonald 013940,* USoMI), golden pothos (*Scindapsus aureus*

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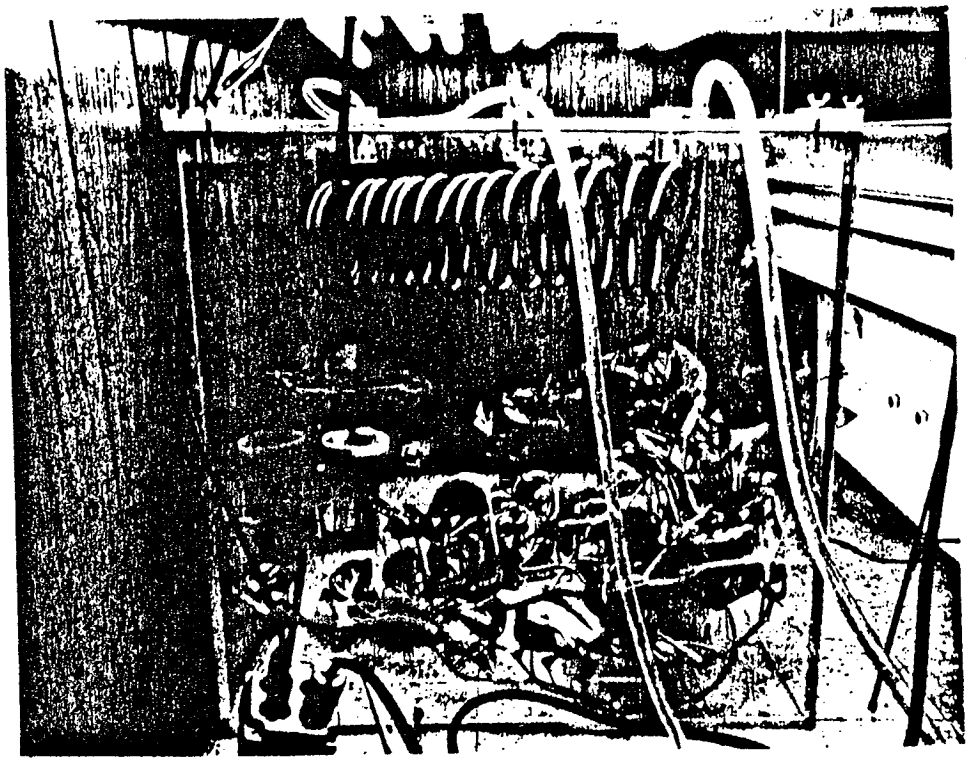

Fig. 1. Plexiglas test chamber containing golden pothos (*Scindapsus aureus*).

(Linden & André) Engl.) (*McDonald 013943*, USoMI), and nephthytis (*Syngonium podophyllum* Schott.) (*McDonald 013944*, USoMI), low light-requiring houseplants, were enclosed under controlled environmental conditions.

EXPERIMENTAL METHODS AND MATERIALS

A clear, cubical chamber (Fig. 1), measuring 73.7 cm on each inside edge and constructed of 12.7 mm (0.5 in) thick Plexiglas, was used to contain the plants in a sealed environment. The top was removable and fitted with a rubber gasket and clamps to provide an airtight seal. Attached to the top was a copper coil through which water maintained at 20°C was continuously circulated in order to regulate the temperature and humidity inside the chamber. The artificial lights were General Electric wide spectrum growth lights that remained on continuously. The average irradiance on the leaf surface of the plants through the Plexiglas top was 3,500 lux (325 fc). A battery-operated fan was placed in the chamber for continuous air circulation. A special porthole fitted with a septum was used to insert a Bendix disposable cartridge for monitoring formaldehyde in air with the aid of a Bendix calibrated hand pump designed for that purpose. The detectable concentration range of the Bendix cartridge is 2–20 ppm formaldehyde.

The air in the chamber was contaminated with formaldehyde by pumping air into the chamber via a gas scrubbing apparatus half-filled with a 37% formaldehyde

solution. The chamber formaldehyde concentration was manipulated by varying the length of time that air was bubbled through the formaldehyde solution.

After contamination, the chamber was allowed to equilibrate for 5 min and the initial formaldehyde concentration measured. The formaldehyde concentration was periodically analyzed in the same manner from that point on.

The chamber temperature from a thermometer placed inside the chamber and the barometric pressure were recorded at the time of each formaldehyde measurement. It was assumed that the pressure inside the chamber was equal to the atmospheric pressure.

The plants used in these experiments were acclimated for several weeks to approximately the same environmental conditions of lighting and temperature to minimize any stress resulting from the closed environment. The volume of each pot was estimated by measuring the volume of water that a similar pot could hold. The total leaf surface area of each plant used in these experiments was determined by tracing the shape of each leaf on paper of uniform consistency, cutting the tracings out and weighing them. The surface area was calculated from the total weight of the tracings and the average cm^2/g of the paper.

Control experiments were conducted prior to placing plants in the system. These experiments were conducted with all the equipment in place except plants. Controls with and without pots containing soil were conducted to determine the degree potting soil containing microorganisms acts as a sink in sorbing formaldehyde. The air was contaminated with formaldehyde and monitored initially and after 6 and 24 h. The system proved to be airtight with no loss of formaldehyde in the plant-free and pot-free formaldehyde control experiments.

Experiments were then conducted with *Scindapsus aureus, Syngonium podophyllum,* and *Chlorophytum elatum* var. *vittatum.* In each experiment, 2 plants of the same species potted in containers with 3.8 l (1 gal) volumes each were enclosed in the chamber. The effective volume of contaminated air (V_{ca}) was calculated to account for all items that reduced the chamber void volume excluding the volume of the emergent leaf biomass. The V_{ca} was corrected to STP [standard temperature, 0°C or 273°K (°K = T, °C + 273°), and pressure, 760 mm] according to the gas law relationship of:

$$\frac{V_1P_1}{T_1} = \frac{V_2P_2}{T_2}.$$

RESULTS AND DISCUSSION

The first 2 sets of experiments were performed to verify system closure and determine the sorbance capacity of the potting soil. The empty chamber proved to be effectively sealed by its ability to maintain a constant formaldehyde concentration of 17 ppm over a 24-h period as shown in Table 1. The second set of experiments in which 2 pots filled with a commercial potting soil mix demonstrated that the potting soil would sorb formaldehyde from air by reducing the formaldehyde from 15 to 10 ppm in 24 h. The results are consistent with those of other investigators in which soil is confirmed to act as a sink for carbon monoxide and other gases and volatile chemicals (Smith et al., 1973). Potting soil

TABLE 1. MEAN DATA FOR CONTROLS (WITH AND WITHOUT SOIL-FILLED POTS) AND FOLIAGE PLANT EXPERIMENTS.

Experiment	Formaldehyde, ppm 0 h	6 h	24 h	V_a, l*	Temp °C	Barometric pressure, mm	Mean leaf surface area, cm²	No. of replicates
Controls w/o pots	17	17	17	362	28.3	765	0	3
Controls w/pots	15	12	10	356	28.0	765	0	3
Scindapsus aureus	18	9	6	354	29.2	765	9,340	7
Syngonium podophyllum	18*	9	6	355	27.8	764	8,549	6
Chlorophytum elatum var. *vittatum*								
Set 1	14	2	<2	356	26.3	763	7,086	7
Set 2	37	8	<2	359	23.8	763	6,135	3

* Corrected to STP.

is not a sterile medium. Consequently, the natural microbial population will metabolize nonrefractive organics such as formaldehyde and restore the soil's capacity to sorb organics.

The formaldehyde concentration in the chamber decreased by 50% to 9 ppm with the *Scindapsus aureus* and *Syngonium podophyllum* in the first 6 h and leveled off at 6 ppm during the exposure period between 6 and 24 h. In the first set of experiments with *Chlorophytum elatum* var. *vittatum*, the formaldehyde concentration decreased rapidly from 14 to 2 ppm in 6 h and below the detection limit of 2 ppm in the interval between 6 and 24 h. Due to these unexpected results, another set of experiments were conducted with the *Chlorophytum elatum* var. *vittatum* in which the formaldehyde initial concentration was increased to 37 ppm. After 6 and 24 h, the formaldehyde measured 8 and <2 ppm, respectively.

The total mass of formaldehyde in the chamber atmosphere at each monitoring interval was computed in Table 2. One μl of formaldehyde at STP has a mass of 1.339 μg. *Scindapsus aureus* and *Syngonium podophyllum* can sorb and/or effect the removal of 0.46 and 0.50 μg CH_2O/cm^2 leaf tissue area, respectively, in a 6-h photoperiod. The *Chlorophytum elatum* var. *vittatum* effected 4.7 times more formaldehyde removal or 2.27 $\mu g/cm^2$ than either of the other 2 species studied

TABLE 2. TOTAL FORMALDEHYDE MASS AND THE CHANGE IN MASS (Δ) AT EACH INTERVAL PER AREA LEAF TISSUE.

Experiment	Total formaldehyde (μg) 0 h	6 h	24 h	Δ formaldehyde/area leaf tissue, μg/cm² 6 h	24 h
Controls w/o pots	8,240	8,240	8,240	—	—
Controls w/pots	7,150	5,720	4,767	—	—
Scindapsus aureus	8,532	4,266	2,844	0.46	0.61
Syngonium podophyllum	8,556	4,278	2,852	0.50	0.67
Chlorophytum elatum var. *vittatum*					
Set 1	6,674	953	<953	0.81	>0.81
Set 2	17,790	3,846	<961	2.27	>2.74

to date under the same conditions. In addition, *Chlorophytum elatum* var. *vittatum* is capable of sorbing atmospheric formaldehyde down to lower levels.

As discussed in the introduction, a representative energy-efficient home with furniture was found to sustain an average formaldehyde concentration of 240 $\mu g/m^3$ with an 0.2 ach. Therefore, on an average, 48 $\mu g/m^3$ are outgassed every hour or 1,152 μg $CH_2O/m^3/d$. An average home of 167 m^2 heated area with 2.5 m ceilings (1,800 ft^2 with 8-ft ceilings) has a total volume of 418 m^3 and would

Based on 2.27 µg of formaldehyde removal per cm^2 of leaf surface area with 7,086 cm^2 per plant approximately 15 spider plants rather than 70 plants could possibly be used.

volatile chemicals as efficiently as the spider plant.

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